SN 1997bs in M66: Another Extragalactic η Carinae Analog?[1]

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ABSTRACT

We report on SN 1997bs in NGC 3627 (M66), the first supernova discovered by the Lick Observatory Supernova Search using the 0.75-m Katzman Automatic Imaging Telescope (KAIT). Based on its early-time optical spectrum, SN 1997bs was classified as Type IIn. However, from the $BVRI$ light curves obtained by KAIT early in the supernova's evolution, and F555W and F814W light curves obtained from *Hubble Space Telescope* archival WFPC2 images at late times, we question the identification of SN 1997bs as a *bona fide* supernova, but instead believe that it is more likely a super-outburst of a very massive luminous blue variable star, analogous to η Carinae and similar to SN 1961V in NGC 1058 (Filippenko et al. 1995 [AJ, 110, 2261]). The progenitor may have survived the outburst, since the SN is seen in early 1998 at $m_{\rm F555W} = 23.4$, about 0.5 mag fainter than the progenitor identified by Van Dyk et al. (1999, [AJ, 118, 2331]) in a pre-outburst image. Based on analysis of its environment in the *Hubble Space Telescope* images, the progenitor must have formed in relative isolation, unlike η Carinae. The recent discovery of additional objects with properties similar to those of SN 1997bs suggests that the heterogeneous class of Type IIn supernovae consists in part of "impostors."

Subject headings: supernovae: general; supernovae: individual (SN 1997bs); stars: evolution; stars: variables: other; galaxies: spiral; galaxies: individual (M66, NGC 3627); galaxies: stellar content

1. Introduction

The ultimate fate of the most massive stars in our Galaxy and other galaxies is still not well understood. The post-main-sequence evolution of stars with masses $M \gtrsim$ 20–30 $M_\odot$, theoretically, should take them possibly through the red supergiant phase, or directly to the luminous blue variable (LBV) phase, en route to becoming hydrogen-deficient or hydrogenless Wolf-Rayet stars toward the end of their lives (e.g., Langer et al. 1994; Stothers & Chin 1996). Although the number of known examples of LBVs is small (Humphreys & Davidson 1994), the spectacular cases of η Carinae (e.g., Davidson & Humphreys 1997) and the Pistol Star (Figer et al. 1998, 1999) show that they go through spectacular eruptive phases of mass ejection. It is assumed that very massive stars ultimately explode as supernovae (SNe; e.g., Woosley, Langer, & Weaver 1993), but it is still possible that they "fail" to become supernovae and core collapse to directly form black holes (MacFadyen & Woosley 1999).

The spectroscopic characteristics of SNe have been recently reviewed by Filippenko (1997). In brief, Type I SNe (SNe I), lacking hydrogen in their optical spectra, divide into the classical SNe Ia, which probably arise from exploding white dwarf stars, and SNe Ib/c, which appear to be more closely related to Type II SNe. All SNe II show hydrogen in their optical spectra and are thought to arise from the explosions of massive stars ($M \gtrsim 8\ M_\odot$). Great variation exists in the strength and profile of the hydrogen lines of SNe II. A growing number of "peculiar" SNe II show a hydrogen emission-line combination of a narrow component atop a broader component (sometimes having a complex shape), with no P-Cygni-like absorption trough. These are the SNe II-"narrow" (SNe IIn; Schlegel 1990; Filippenko 1991).

As of 2000 May, 43 SNe IIn have been identified (from the online Asiago SN Catalog[2] and the IAU Circulars). The Balmer emission has been interpreted as arising from interaction of the SN ultraviolet radiation and the SN ejecta with a dense circumstellar medium set up by the progenitor in a pre-SN phase. Evidence is accumulating that SNe IIn arise from very massive stars (e.g., Weiler, Panagia, & Sramek 1990; Sollerman, Cumming, & Lundqvist 1998). It seems likely that the old Zwicky (1965) "Type V" SNe, examples of which include SNe 1954J and 1961V and which are now generally considered to have been peculiar SNe II (Doggett & Branch 1985; Filippenko 1991), are related to SNe IIn. For instance, SN 1986J, a prototypical SN IIn, was originally classified as Type V (Rupen et al. 1987). However, particularly in the case of SN 1961V (Goodrich et al. 1989; Filippenko et al. 1995), it appears that not all of the Zwicky types were genuine SNe, strictly defined to be the violent destruction of a star at the end of its life. By extension, then, it is intriguingly possible that not all SNe IIn are real SNe. Some SNe IIn could represent a pre-SN cataclysmic event of a very massive star. This "contamination" of the SN IIn subtype complicates calculations of the production rate of neutron stars and the chemical evolution of galaxies, and adds a new wrinkle in the evolution of the most massive stars.

In this paper, we discuss the example of the SN IIn 1997bs in NGC 3627 (M66). SN 1997bs was the first SN discovered by the Lick Observatory Supernova Search (LOSS, the direct successor of the former search at Leuschner Observatory), which is robotically conducted with the 0.75-m Katzman Automatic Imaging Telescope (KAIT; see Filippenko et al. 2000). Treffers et al. (1997) reported the SN discovery, from an image (Figure 1) obtained on 1997 April 15 (UT dates are used throughout this paper). The SN brightness at discovery was roughly estimated to be $R \simeq 17$ mag. An image from April 10 did not show anything at the location of SN 1997bs, to a limiting magnitude $R \simeq 17.6$. The

[2] http://merlino.pd.astro.it/~supern/snean.txt

position of the SN is RA=$11^h20^m14\overset{s}{.}25$, Dec=$+12°58'19\overset{''}{.}6$ (J2000.0; Cavagna 1997), which is about $11\overset{''}{.}2$ west and $69\overset{''}{.}9$ south of the galaxy's nucleus. NGC 3627 has been host to two other known SNe, the Type II SN 1973R (Ciatti & Rosino 1977) and the Type Ia SN 1989B (Wells et al. 1994). Here we present evidence that SN 1997bs was not a genuine SN, through spectroscopic and photometric observations made at Lick and also photometry from archival *Hubble Space Telescope* (*HST*) images.

2. Observations

2.1. Lick Spectroscopy

A CCD spectrum of SN 1997bs was obtained with the Lick 3-m Shane reflector on 1997 April 16 by Filippenko, Barth, & Gilbert (1997), over the range 3200 to 8000 Å with a resolution of about 7 Å (Figure 2). It is dominated by relatively narrow (FWHM $\simeq$ 1000 km s^{-1}) Balmer emission lines on a featureless continuum. Many weaker Fe II emission lines are also evident. From this spectrum, Filippenko et al. classified SN 1997bs as Type IIn.

2.2. KAIT Photometry

BVRI photometry was obtained with KAIT over about 60 days following discovery before it was no longer detectable. Images of NGC 3627 in each of the four bands were obtained on 1994 January 13 at the KPNO 2.1-m telescope by L. A. Wells (who kindly provided them to us). These pre-SN images served as "templates" which were subtracted from the SN images in each of the four bands (see Filippenko et al. 1986; Richmond et al. 1995). First, for each band, the template was registered to a SN image, so that stars in the field were aligned, and the template image was convolved with a Gaussian to match the FWHM of stars in the SN image. Then, the stars in the template image were flux-scaled to match the stars in the SN image, and, finally, the template was subtracted from the SN image, leaving behind a residual image containing only the SN. This procedure was followed for each observational epoch. Photometry of the SN in each band and for each epoch was done on the template-subtracted image using the APPHOT package in IRAF[3]. Measurements of the field stars "3" and "4" (see Wells et al. 1994) were also obtained from the unsubtracted images in each band for each epoch, this time determining the sky background from an annulus around each field star.

In addition, *BVRI* images of NGC 3627 were obtained on 1999 December 17 with the 1.5-m telescope at Palomar Observatory, under photometric conditions. In Table 1 we list the magnitudes in each band for stars "3" and "4" derived from the Palomar observations. The agreement with the values given in Table 2 of Wells et al. (1994) for these stars is quite good. With our magnitudes for these stars we then transformed the KAIT photometry of SN 1997bs onto the Johnson-Cousins system.

2.3. *HST* Archival Image Photometry

Deep *HST* WFPC2 images of NGC 3627 in the bands F555W and F814W were obtained from the image archive. These images were made in pairs (to facilitate removal of cosmic rays) between late 1997 and early 1998 during several epochs. They were originally intended to measure the distance to the galaxy using Cepheid variables (GO program 6549), with the goal of determining the absolute magnitude of SN 1989B (Saha et al. 1999; their Table 1 lists the exposures). Saha et al. identify SN 1997bs as variable star "C2-V23," yet

[3]IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

they did not recognize it as the SN and note only that C2-V23 and others "are definitely variable ..." and "...may be transient variables such as novae."

In addition, a cosmic-ray split pair of WFPC2 F606W images made on 1994 December 28 was also obtained from the archive. Van Dyk et al. (1999; their Figure 7) show this image pair, as well as sample F555W images, showing the SN.

To measure the brightness of SN 1997bs in the WFPC2 images, we employed point-spread function (PSF) fitting photometry performed by DAOPHOT (Stetson 1987) and ALLSTAR within IRAF. We used the *Tiny Tim* routine (Krist 1995) to produce an artificial PSF, simulated to have stellar spectral type A and PSF radius $0\farcs5$. The artificial PSF was created at the pixel position of the SN in the archive images. Since the stellar profiles in the images were actually somewhat broader than the artificial PSF, the latter was broadened using a Gaussian to match the former. Instrumental photometry was aperture corrected, using measurements of artificial stars of known magnitudes placed randomly in the field, and converted to magnitudes using the photometric synthetic zeropoints in Holtzman et al. (1995; their Table 9), appropriate for a $0\farcs5$ aperture radius. A correction for the gain ratio to the 7 e^- ADU^{-1} gain state was applied.

3. Results

In Table 3 we list the KAIT photometry for SN 1997bs, while Table 4 gives the photometry derived from the archival *HST* F555W and F814W images. Our *HST* photometry of SN 1997bs agrees quite well with that from Saha et al. (1999; their Table 3), to within 0.02 mag at F555W and 0.04 mag at F814W.

In Figure 3 we show the combined *BVRI* light curves for the SN, including both the KAIT and *HST* photometry. The F555W and F814W measurements correspond approximately to V and I magnitudes, respectively. These WFPC2 synthetic magnitudes were *not* converted to the Johnson-Cousins system following (for example) the transformations given by from Holtzman et al. (1995); for an emission-line object such as SN 1997bs, this conversion may not be entirely correct or appropriate.

SN 1997bs was apparently discovered before maximum brightness in R, and generally at or near maximum in the other bands. The SN light curves decline from peak brightness over the next ~20 days by ~1 mag. The decline is less drastic after JD ~2450580 in V. In R and I, the light curves appear to reach a plateau of roughly constant magnitude in each band. (The observational coverage in B terminates after JD 2450582.) The KAIT photometry in all bands ends on JD 2450617, after a span of nearly 60 days of monitoring.

There is a long, ~150-day gap in our coverage before we are able to extend the light curves using the *HST* photometry in (approximately) V and I bands. It is apparent in V that the light curve began a much steeper decline again on or before JD 2450765; the slope of the decline is quite similar to the slope of the earlier post-maximum decline. The V light curve, again, achieves a more gradual decline after about JD 2450786. In fact, after JD 2450804, the V magnitude of the SN appears to reach another plateau, at ~23.4 mag. The I light curve at late times appears to gradually decline, at a slower rate than the earlier post-maximum decline (the SN is partially saturated in the first-epoch F814W image, so we can only give a lower limit to its brightness).

In Figure 4 we show the color evolution of the SN. For the first 60 days, the SN color becomes generally redder after discovery. This is best exemplified by the evolution of the $V-I$ color, which near maximum already is at $V-I \simeq 0.62$ mag, but, even before the end of KAIT monitoring, has reached $V-I \simeq 1.43$ mag. By the time monitoring resumes, with the inclusion of the *HST* data, the SN is very red, at $V-I \sim 3.4$ mag. The red color of the SN is obvious in the color composite image shown by Saha et al. (1999; their Figure 1).

The SN possibly may have been much redder than this prior to its recovery in the *HST* images: it becomes bluer at late times, to $V - I \approx 3$ in the last F555W/F814W image pair.

4. Discussion

Although the spectrum of SN 1997bs indicates that it is a SN IIn, its photometric nature is highly unusual, both in the behavior of the light curves and in absolute magnitude.

Since the distance modulus of NGC 3627 has been measured with Cepheids ($\mu = 30.28$ mag; Saha et al. 1999), we can adjust our observed light curves of SN 1997bs to an absolute scale. We would like to correct the absolute light curves for extinction, but the amount of reddening toward SN 1997bs is not known. The Galactic foreground reddening toward NGC 3627 is $E(B-V) = 0.03$ mag (Schlegel et al. 1998). However, SN 1997bs occurred at the edge of a dust lane in NGC 3627, so it is likely that reddening internal to the galaxy at the site of the SN is appreciable and spatially variable. We have attempted to estimate the reddening, based on the colors of stars in the SN environment (see below), yet the stellar colors, particularly for the bluest stars, are consistent with the foreground reddening estimate.

From the light curves, we find that the $B - V$ color near maximum was 0.67. If the intrinsic color was close to $B - V = 0.0$, which is what one might expect for SNe II, then $E(B - V) \simeq 0.7$. However, the spectrum of SN 1997bs dereddened by this amount would make the SN continuum unphysically blue, so already we know the reddening cannot be this large. The emission line intensity ratios of Hα/Hβ/Hγ are 2.6/1.0/0.5, which, if anything, are slightly flatter than what one expects for Case B recombination (2.8/1.0/0.47); so, there is no evidence for reddening of the emission lines. We measure an equivalent width of 1.8 Å for the narrow Na I D absorption line at the redshift of the SN (unfortunately, the two line components are not resolved). Though with low-resolution spectra one cannot confidently translate this into a reddening (one actually needs high-dispersion spectra), an analysis similar to that of Filippenko, Porter, & Sargent (1990) suggests a reddening of $E(B-V) = 0.38$ mag. Moreover, when this type of analysis was applied to the SN Ic SN 1987M by Jeffery et al. (1991), they argued that it overestimates $E(B-V)$ by a factor 1.8. If we scale our estimate for SN 1997bs by this factor, then $E(B-V) = 0.21$ mag. We assume this value to be the total reddening to the SN and correct the observed light curves for it, using a standard Galactic reddening law (Cardelli, Clayton, & Mathis 1989), $A_V = 3.1E(B-V)$.

SN 1997bs appears to be unusual with respect to most other SNe II (or other SN types), due to its very low absolute magnitude: maximum for the SN was at only $M_V \simeq -13.8$, about 4 to 4.5 mag fainter than a typical SN II.

In Figure 5 we show the object's unusual photometric evolution through a comparison of the absolute V light curves of SN 1997bs and of the SNe IIn 1988Z (Turatto et al. 1993), 1987B (Schlegel et al. 1996), and 1994Y (Ho et al. 2000). (Distances to the latter three SNe were calculated from their recession velocities, obtained from the NASA/IPAC Extragalactic Database and an assumed distance scale $H_0 = 65$ km s^{-1} Mpc^{-1}. No extinction corrections have been applied for these SNe). The light curves of the three comparison SNe IIn have been scaled, so that their maximum observed brightness occurs at approximately the same epoch as SN 1997bs. One can see that, besides the obvious underluminosity, the post-maximum decline of SN 1997bs is very different in behavior from that of the other SNe.

One also notices from Figures 5 and 6 that, at late times, the F555W light curve (in particular) appears to reach a plateau once again, at ~ -7.5 mag (or $\sim$23.4 mag from Figure 3). None of the other SNe IIn, particularly SN 1994Y, show this sort of behavior.

Van Dyk et al. (1999) found in the F606W image from 1994 December 28, about 27.5 months *before* the discovery of SN 1997bs, a star at the exact position of the SN, with $m_{\rm F606W} = 22.86 \pm 0.16$ mag. Assuming $m_{\rm F606W} \sim V$, at the distance of NGC 3627, and corrected for our assumed reddening, the star had an absolute magnitude $M_V \simeq -8.1$. Van Dyk et al. associated this star with the progenitor of SN 1997bs. Its absolute magnitude is consistent with an extremely luminous supergiant star. The late-time brightness of SN 1997bs is ~0.5 mag fainter than the brightness of this precursor star (Figure 6). However, the unusual apparent flattening-out of the late-time light curve suggests that the star *may* have survived the explosion. SN 1961V (discussed below) also showed a flattening of this type, before fading considerably a few years later, probably due to the formation of dust in the ejected material (Goodrich et al. 1989; Filippenko et al. 1995).

This raises the question of whether or not SN 1997bs was really a *bona fide* supernova, or instead was something altogether different. We have more thoroughly analyzed the *HST* images containing SN 1997bs by producing very deep images in both the F555W and F814W bands through coaddition of the individual images taken at the various epochs. The results are a 24500-s total exposure in F555W and a 12500-s exposure in F814W. We show the F555W total image in Figure 7. For the distance modulus $\mu = 30.28$ measured by Saha et al. (1999), $1'' = 55$ pc. For the WFPC2 chip, then, one pixel$\simeq$6 pc. At this resolution, it is difficult to distinguish a single object from a blend of several contiguous ones, so it is possible that the SN progenitor could have exploded among a small, compact star cluster, and that now we see the surviving cluster minus the progenitor. With the available data, we cannot rule out this possibility.

We believe, however, that the evidence presented in this paper indicates that SN 1997bs was more likely the super-outburst of a very massive LBV star, possibly analogous to the enormous eruptions experienced by η Carinae (Davidson & Humphreys 1997). The V

light curve, in particular, shows that SN 1997bs brightened by nearly 6 magnitudes before fading, possibly through the formation of optically thick dust, given how red it became.

We have analyzed the environment of SN 1997bs by measuring the magnitudes, using the PSF-fitting techniques described above in §2.3, of the stars in a $20''$ (north-south) $\times$ $12''$ (east-west) region centered on SN 1997bs. Figure 8 shows the resulting color-magnitude diagram. We have overlaid the theoretical isochrones for solar metallicity from Bertelli et al. (1994), converting them, as in Van Dyk et al. (1999), from the Johnson-Cousins system to the WFPC2 synthetic magnitude system. We also converted the reddening and extinction to the WFPC2 synthetic system.

Although many young (massive) dwarf and supergiant stars are resolved in this larger area, and the abundance of dust and luminous stars in the environment implies recent massive star formation, the stars within $\sim1''$ ($\sim$55 pc) of SN 1997bs are older, less luminous giant and supergiant stars. Regardless of whether or not the progenitor of SN 1997bs has survived the outburst, the star (or possible surviving compact star cluster) seems to have formed in relative isolation, unlike the case of η Car, which formed among clusters of young massive stars of similar age (Davidson & Humphreys 1997). Part of the environmental analysis is to try to estimate the mass of the progenitor star, based on the properties of other stars in its vicinity, much the same way as in Van Dyk et al. (1999). Based on the diagram in Figure 8, we are unable to place a meaningful constraint on the mass of the SN 1997bs progenitor. To perform a more complete assessment of the massive star population in the vicinity of SN 1997bs, and to determine whether the progenitor alone survived, or is among a surviving star cluster, higher-resolution U and B images must be obtained, since, in particular, $V - I$ is a poor discriminant of hot stars. These blue images would also provide a better estimate of the extinction toward the SN.

SN 1997bs is not alone in its unusual characteristics. A similar object may be the peculiar SN IIn 1961V in NGC 1058. SN 1961V was originally classified as "Type V" by Zwicky (1965) and had probably the most bizarre light curve ever recorded for a SN. Its progenitor was identified as a very luminous star, $M^0_{\rm pg} \approx -12$ mag, visible in many photographs of NGC 1058 prior to the explosion (Bertola 1964; Zwicky 1964; Klemola 1986). Goodrich et al. (1989) and Filippenko et al. (1995) identified the possible survivor of the SN 1961V event, the latter study via *HST* WFPC imaging, and both studies conclude that perhaps SN 1961V was not a genuine supernova, but rather also the super-outburst of a luminous blue variable, similar to η Car.

Other examples possibly include SN 1954J, also known as "Variable 12" in NGC 2403 (Humphreys & Davidson 1994), SN 1999bw in NGC 3198 (Filippenko, Li, & Modjaz 1999), and SN 2000ch in NGC 3432 (Filippenko 2000). SN 1999bw appears to have similar spectral characteristics to SN 1997bs and is also quite subluminous. SN 2000ch is similar, but may have experienced a shorter-lived outburst than did SN 1997bs (Hudec et al. 2000).

The SN IIn subclass clearly spans a very broad range of properties, as was already known to some extent (e.g., Filippenko 1997). If the conclusions of this paper are correct, and the progenitor of SN 1997bs survived, then the "explosion" mechanism is *not* core collapse in all SNe IIn. That is, the subclass appears to include a number of supernova "impostors" such as SN 1997bs, which are evolved but still living. For SN 1997bs, a more definitive test will be whether the star remains visible in future *HST* images obtained years after the outburst (although, even if it survived, it might fade at optical wavelengths, due to the formation of dust in the ejecta; see Goodrich et al. 1989). The occurrence of SN 1997bs and its possible cousins, SNe 1961V, 1954J, 1999bw, and 2000ch and their resemblance to LBV super-outbursts begs the question of the ultimate fate of these very massive stars.

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Table 1. Comparison Star Magnitudes and Colors

Star[a]	V	$B-V$	$V-R$	$R-I$
3	16.24	0.53	0.32	0.37
4	15.95	0.61	0.36	0.41

[a]The star numbers are those designated by Wells et al. (1994).

Table 2. KAIT Photometry of SN 1997bs[a]

UT Date	JD	B	V	R	I
1997 Apr 10.27	2450548.77	···	···	>17.6	···
1997 Apr 15.21	2450553.71	···	···	16.93(03)	···
1997 Apr 16.27	2450554.77	17.79(11)	17.12(04)	16.85(02)	16.45(03)
1997 Apr 22.31	2450560.81	18.06(12)	17.22(07)	16.83(03)	16.48(04)
1997 Apr 26.22	2450564.72	17.88(05)	17.18(03)	16.87(02)	16.46(02)
1997 Apr 28.22	2450566.72	···	17.28(04)	16.97(02)	···
1997 Apr 30.21	2450568.71	18.04(07)	17.43(06)	17.01(03)	···
1997 May 02.30	2450570.80	18.07(10)	17.40(04)	17.06(02)	16.57(05)
1997 May 03.24	2450571.74	···	17.57(17)	17.21(08)	16.73(05)
1997 May 04.20	2450572.70	18.20(18)	17.61(07)	17.16(04)	···
1997 May 05.20	2450573.70	18.38(16)	17.53(11)	17.30(03)	···
1997 May 06.26	2450574.76	···	···	17.46(04)	···
1997 May 07.20	2450575.70	18.80(08)	17.85(05)	17.59(02)	17.16(04)
1997 May 10.33	2450578.83	18.97(20)	18.12(06)	17.81(03)	17.28(04)
1997 May 11.31	2450579.81	19.01(06)	18.25(05)	17.89(02)	17.37(04)
1997 May 12.20	2450580.70	19.22(15)	18.31(06)	17.93(03)	17.46(04)
1997 May 13.21	2450581.71	19.18(21)	18.24(08)	17.89(04)	17.39(04)
1997 May 20.21	2450588.71	···	18.44(12)	17.84(04)	17.21(05)
1997 May 21.26	2450589.76	···	18.52(14)	···	17.41(06)
1997 May 31.23	2450599.73	···	18.56(08)	17.86(03)	17.27(04)
1997 Jun 06.24	2450605.74	···	···	17.89(03)	···
1997 Jun 07.26	2450606.76	···	18.68(11)	···	17.25(03)
1997 Jun 11.21	2450610.71	···	···	···	17.32(03)

Table 2—Continued

UT Date	JD	B	V	R	I
1997 Jun 15.22	2450614.72	···	···	···	17.10(12)
1997 Jun 17.22	2450616.72	···	18.75(12)	18.07(05)	···

[a]The values given in parentheses are the uncertainties in the last two digits of the magnitudes.

Table 3. *HST* Photometry of SN 1997bs[a]

UT Date	JD	m_{F555W}	m_{F814W}
1997 Nov 12.67	2450765.14	21.45(03)	$<$18.50
1997 Nov 16.47	2450768.97	21.73(03)	...
1997 Nov 20.04	2450773.54	22.10(03)	...
1997 Nov 28.10	2450780.60	22.50(03)	...
1997 Dec 03.95	2450786.45	22.89(04)	19.49(02)
1997 Dec 08.78	2450791.28	22.96(05)	...
1997 Dec 14.16	2450796.66	23.05(05)	...
1997 Dec 18.80	2450801.30	23.17(05)	19.94(02)
1997 Dec 21.89	2450804.39	23.30(06)	...
1997 Dec 27.67	2450810.17	23.34(05)	20.09(02)
1998 Jan 03.53	2450817.03	23.38(06)	...
1998 Jan 10.46	2450823.96	23.40(05)	20.35(05)

[a]The values given in parentheses are the uncertainties in the last two digits of the magnitudes.

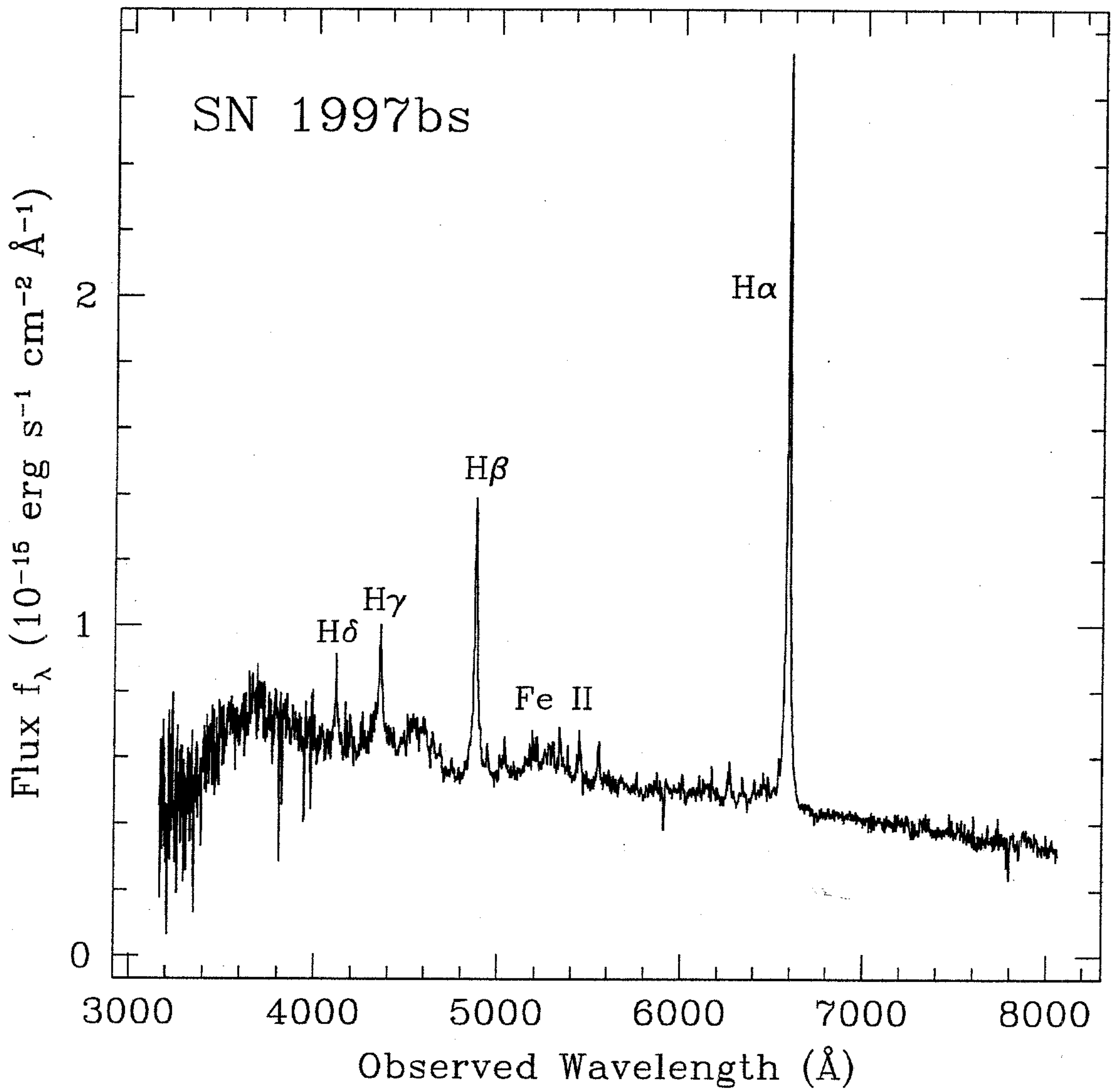

Fig. 2.— Spectrum of SN 1997bs obtained with the Lick 3.0-m Shane reflector on 1997 April 16. The absolute flux scale is approximate.

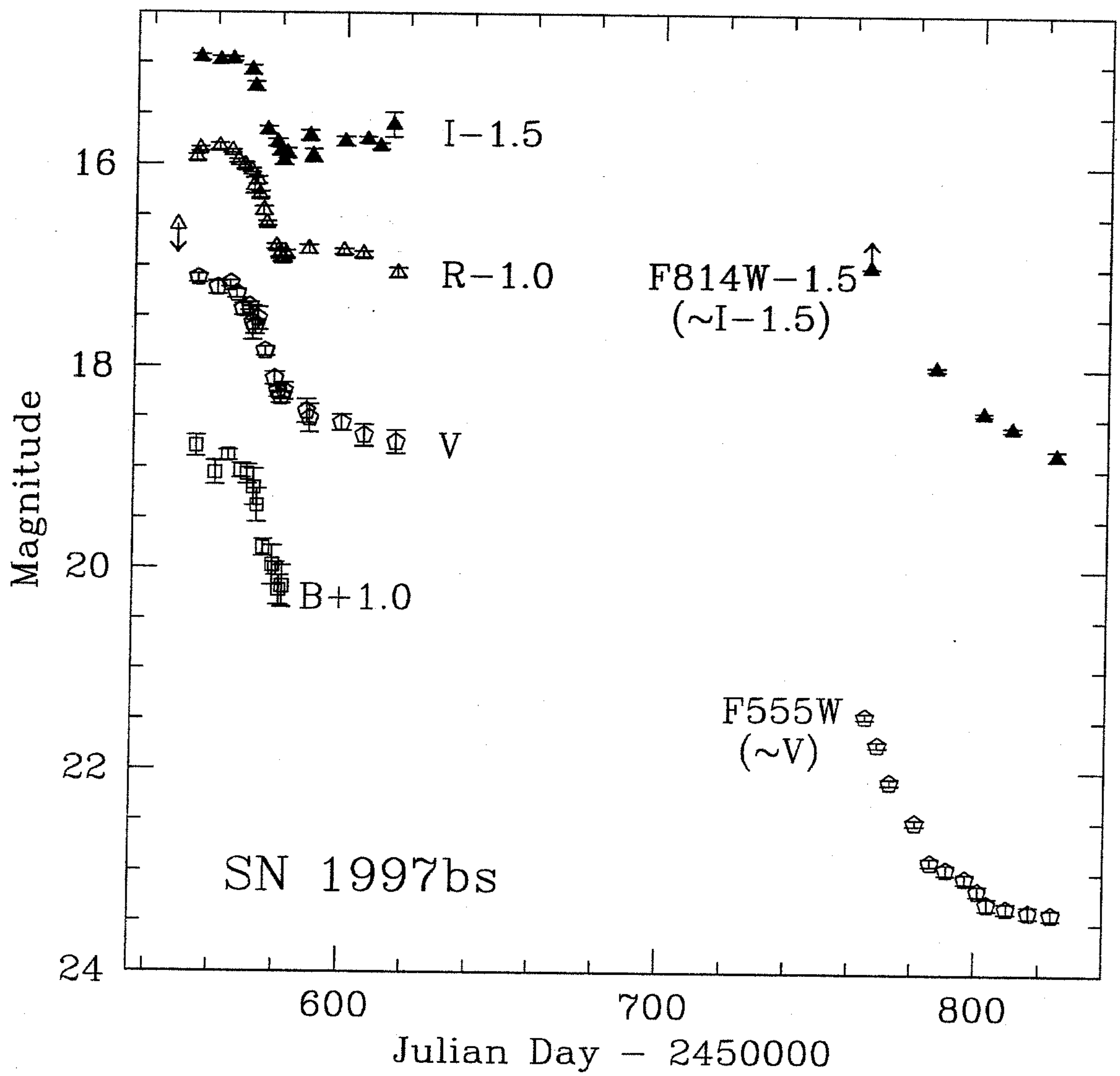

Fig. 3.— *BVRI* light curves for SN 1997bs, obtained with KAIT at Lick Observatory, with the addition of the F555W ($\sim V$) and F814W ($\sim I$) magnitudes obtained from archival *HST* images.

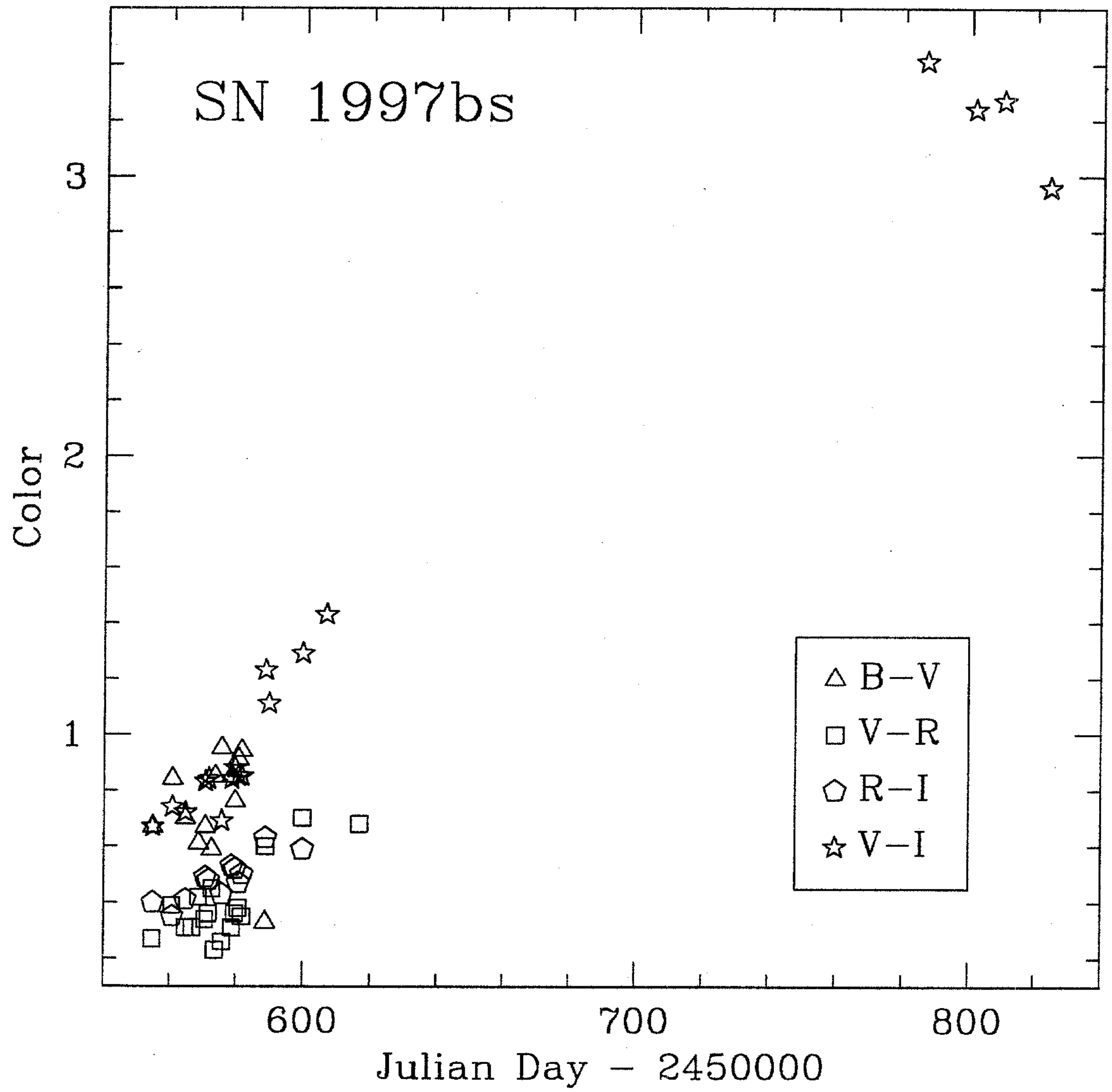

Fig. 4.— The color evolution of SN 1997bs. Shown are the $B-V$ (*triangles*), $V-R$ (*squares*), $R-I$ (*pentagons*), and $V-I$ (*stars*) colors.

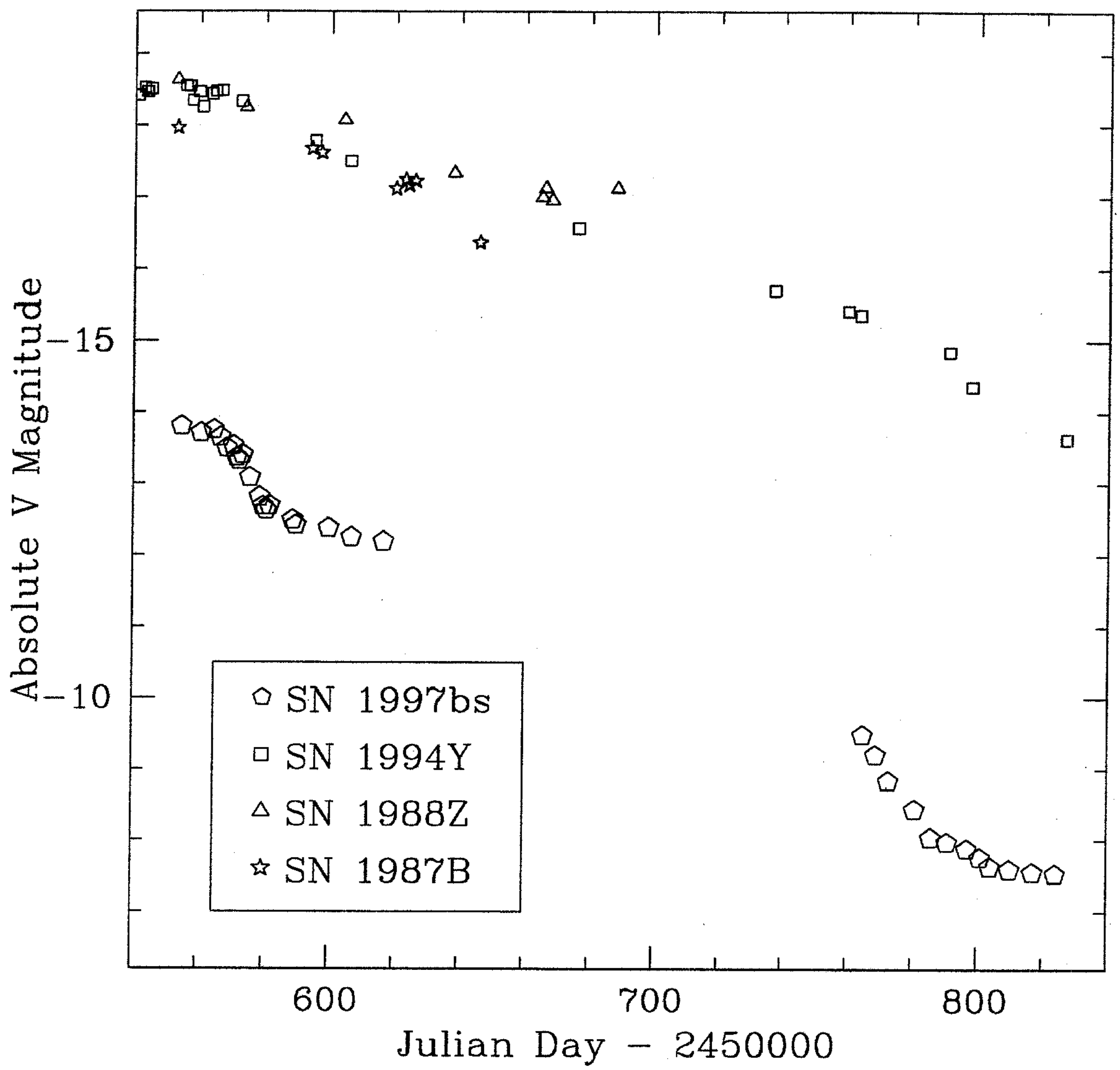

Fig. 5.— A comparison of the absolute V light curves of SN 1997bs (based on the KAIT and *HST* Cepheid observations; *pentagons*) with those of three other Type IIn SNe: SN 1994Y (*squares*; Ho et al. 2000); SN 1988Z (*triangles*; Turatto et al. 1994); and SN 1987B (*stars*; Schlegel et al. 1996). For SN 1997bs, we assume a distance modulus $\mu = 30.28$ mag (Saha et al. 1999) and have dereddened the light curve by $E(B-V) = 0.21$. Note the relatively low luminosity of SN 1997bs.

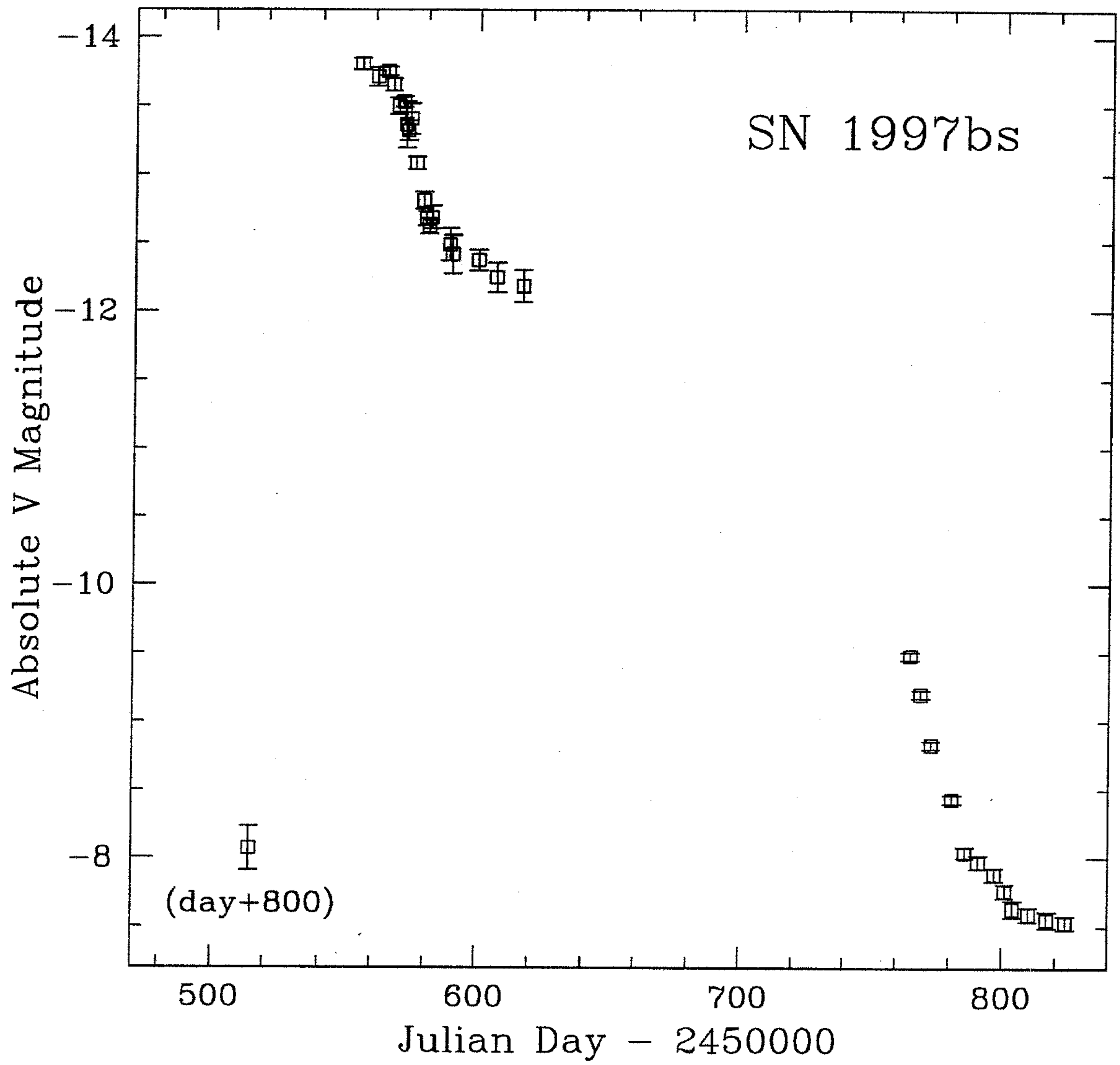

Fig. 6.— Absolute V light curve of SN 1997bs, as in Figure 5, also showing the photometry for the progenitor star from an *HST* archival WFPC2 F606W image made on 1994 December 28 (see Van Dyk et al. 1999; we have added 800 days to this epoch in the figure).

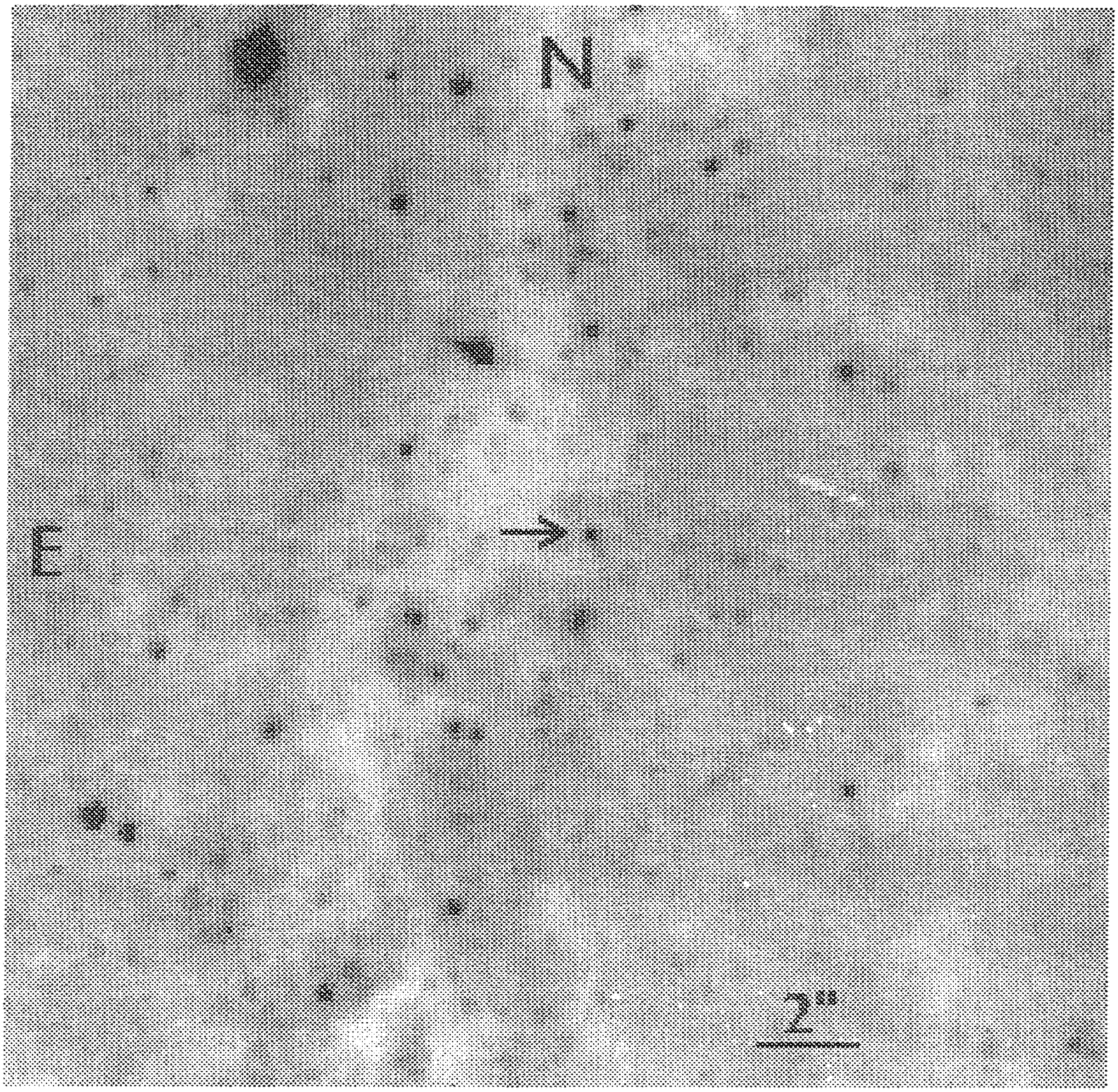

Fig. 7.— The environment of SN 1997bs (indicated by the arrow near the center) on a coadded *HST* archival WFPC2 F555W image.

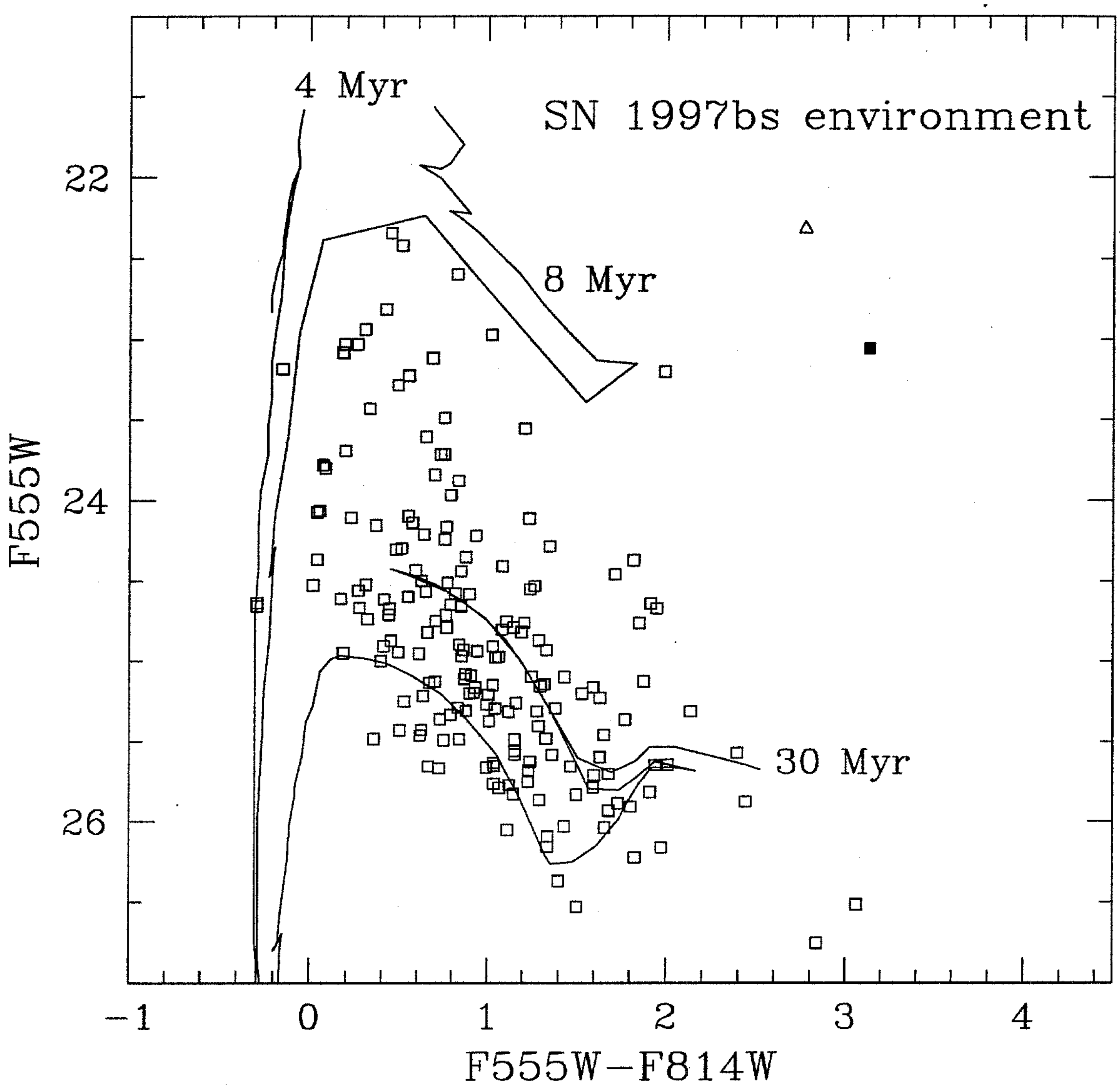

Fig. 8.— Color-magnitude diagram of stars in the environment of SN 1997bs, based on photometry of coadded *HST* archival WFPC2 F555W (~V) and F814W (~I) images. The environment represented covers 20″ (north-south) × 12″ (east-west) centered on the SN. Also shown are isochrones from Bertelli et al. (1994) with solar metallicity for ages 4 Myr, 8 Myr, and 30 Myr. The colors of the bluest stars are consistent with the Galactic foreground reddening, $E(B-V) = 0.03$. The SN is the (time-averaged) point (*filled square*) at F555W≈23.1 and F555W−F814W≈3. The other bright red object (*triangle*), at F555W≈22.3, F555W−F814W≈2.8, is too bright to be a single star and is probably a red, or reddened, compact star cluster.